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Bill Francis, Barbara Dalpke, Thomas Hu, Paul Bicho

Mountain Pine Beetle working paper 2009-29

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Abstract

Previous research at FPInnovations, PAPRICAN indicated that the use of mountain pine beetle-killed wood to produce mechanical pulp (TMP) resulted in a small impact on pulp strength and more pronounced influence on sheet structure (sheet density and roughness) of handsheets (Dalpke et al. 2008; Hu et al. 2009A). Preliminary tests on TMP pulp made from late-grey-stage wood also revealed a potential increase in the linting propensity. However, it was not clear to what extent printing paper quality issues are related to changes in incoming-fibre quality or to changes in processing when using beetle-killed wood.

Peroxide bleaching of grey-stage beetle-killed lodgepole pine required an increased peroxide charge to reach a brightness target, affecting physical properties moderately and effluent load significantly. For sodium hydrosulphite bleaching of green and grey-stage wood, the changes in pulp properties, other than brightness, due to changes in hydrosulphite charge were small and not likely to be felt in a mill setting.

To monitor wood quality entering the mill, an online chip sensor was installed and used to monitor chip properties: bark, extractives, density, pine (blue), pine (clear), spruce, miscellaneous species, moisture and brightness. The chip-sensor calibrations that were developed were good for chip moisture content and miscellaneous species content, and fair for extractives content and pine (blue) content. Good calibrations were not obtained for the remaining five chip properties, in part because of low variability in the calibration samples.

There was large short-term variability of most predicted chip properties, with the exception of chip density and brightness. However, the influence of short-term chip property variability on the unbleached TMP properties was small due to the chip handling and storage between the chip sensor and the TMP operation, which resulted in the chips being mixed within the process and damped the impact of variability. The long-term variability of chip properties was small, and the chip sensor did not detect any major changes in the chip supply over the long term, in terms of bark content, species mix, density, extractives, moisture and brightness.

The unbleached TMP properties were strongly influenced by operating conditions, such as refiner plate time, primary and secondary refining energies, reject refining power and production. These operating effects had a stronger impact on TMP quality than did the incoming-chip quality; as a result, no influence of the variation of chip properties on unbleached TMP properties could be detected. Because no effect of chip-property variability on unbleached TMP properties was detected, the PLS model was not extended to determine effect on bleached TMP and finished paper properties. Further work is needed to determine the impact of quality of chips from mountain pine beetle-killed pine on unbleached TMP and finished paper quality at this mill.

Keywords: mountain pine beetle, mechanical pulp, printing paper, paper quality, sodium hydrosulphite bleaching, alkaline peroxide bleaching, multivariate analysis, chip quality, mechanical pulp quality, online wood chip sensor

Résumé

Des recherches précédentes menées à FPInnovations – PAPRICAN ont démontré que l'utilisation de bois détruit par le dendroctone du pin ponderosa (DPP) pour produire une pâte mécanique (PTM) n'a eu que peu d'incidence sur la résistance de la pâte, mais une influence plus marquée sur la structure (densité et rugosité) des feuilles d'essai. 2008; Hu et coll. 2007A). Des essais préliminaires sur la pâte PTM effectués à partir de bois à la fin du stade gris ont aussi révélé une augmentation possible de la propension au peluchage. Il n'était cependant pas clairement indiqué jusqu'à quel point les problèmes liés à la qualité du papier d'impression se rapportaient aux changements dans la qualité de la fibre d'arrivée ou aux changements de procédure lorsque l'on utilisait du bois détruit par le DPP.

Afin d'aborder les différences dans la réaction au blanchiment occasionnées par l'utilisation de bois détruit par le dendroctone du pin ponderosa, de même que par les changements de protocoles de blanchiment, une pâte écrue faite de pins tordus latifoliés au stade vert, non attaqués par le dendroctone du pin ponderosa, et une pâte provenant de pins tordus latifoliés au stade gris détruits par le dendroctone, ont été blanchies sous différentes conditions, et des feuilles d'essai ont été formées et mises à l'essai afin de déterminer les propriétés physiques. En ce qui concerne le blanchiment à l'hydrosulfite de sodium de bois au stade vert et au stade gris, les changements dans les propriétés de la pâte, autres que le degré de blancheur, attribuables aux changements dans la charge d'hydrosulfite, étaient faibles et non susceptibles d'être ressentis dans le cadre d'une usine. Pour ce qui est du blanchiment au peroxyde d'hydrogène alcalin du bois au stade vert et au stade gris, les propriétés physiques de même que la perte de production et la charge DCO/DBO d'effluent étaient similaires lorsque le blanchiment avait lieu dans les mêmes conditions. Cependant, le bois au stade gris exigeait une charge majorée de peroxyde pour atteindre un degré de blancheur déterminé, affectant à la fois les propriétés physiques et la charge d'effluent. Les changements dans les propriétés physiques, bien qu'ils doivent être pris en compte, étaient modérés. Cependant, l'augmentation dans la charge d'effluent, ainsi que la perte de production prévue étaient notables et seraient constatées à l'usine lors du changement des conditions de blanchiment au peroxyde.

Un capteur de copeaux en direct a été installé dans l'atelier d'essai au-dessus du convoyeur de copeaux entre le crible à copeaux et les silos à copeaux. Le capteur de copeaux mesurait l'infrarouge proche (NIR) du spectre d'absorption à des intervalles de cinq secondes. Ces données spectrales ont été utilisées pour prévoir les propriétés des copeaux en utilisant les modèles PLS 2 (projection pour structures latentes) calibrés pour les conditions spécifiques de l'usine. Les calibrages du capteur à copeaux élaborés étaient bons pour ce qui est du contenu d'humidité des copeaux et du contenu d'essences diverses, et modérés pour ce qui est du contenu de produits d'extraction et du contenu de pin (bleu). De bons calibrages n'ont pas été obtenus pour cinq autres propriétés des copeaux, en partie à cause de la faible variabilité des échantillons de calibrage. L'efficacité prédictive du modèle peut être améliorée en utilisant des échantillons de calibrage comportant une plus grande variabilité.

Des modèles multivariables ont été réalisés en rapprochant les propriétés de la pâte thermomécanique (PTM) non blanchie avec les propriétés des copeaux déterminées à partir du capteur de copeaux en direct et des données d'opération PTM. L'influence de la variabilité à court terme des propriétés des copeaux sur les propriétés de la PTM non blanchie était faible, en raison de la manutention et de l'entreposage des copeaux entre le capteur de copeaux et l'opération de PTM causant, avec le temps, une dispersion des copeaux et un affaiblissement de l'incidence. En outre, les propriétés de la PTM non blanchie étaient fortement influencées par les conditions d'opération comme le temps de rétention des disques de défibrage, les énergies primaires et secondaires du défibrage, la puissance de défibrage rejetée, et la production. Ces effets d'application ont eu une incidence plus forte sur la qualité de la PTM qu'en a eue la qualité

des copeaux d'arrivée; par conséquent, aucune influence de la variation des propriétés des copeaux sur les propriétés de la PTM non blanchie n'a pu être détectée. D'autres travaux sont nécessaires pour déterminer l'incidence de la qualité des copeaux de bois ravagés par le dendroctone du pin ponderosa sur la PTM non blanchie et la qualité du papier fini à cette usine.

Mots clés : dendroctone du pin ponderosa, pâte mécanique, papier d'impression, qualité du papier, sodium, analyse multivariable, qualité des copeaux, qualité de la pâte mécanique, capteur de copeaux de bois en direct ; blanchiment à l'hydrosulfite de sodium, blanchiment au peroxyde d'hydrogène alcalin

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1 Introduction

The mountain pine beetle epidemic in British Columbia continues to take a toll on the province's pulp and paper industry. With the beetle infestation becoming more widespread in Alberta, it is expected that Alberta mills will see more of an impact in the near future. Almost all of the mills in British Columbia's interior and some on the coast, as well as some Alberta mills, have experienced an increase in mountain pine beetle-killed pine entering their process streams, with some mills running up to 90% beetle-killed wood. Furthermore, the proportion of older, grey-stage material is increasing. With vast volumes of beetle-killed wood currently standing in forests, and the beetle infestation likely to spread further in the coming years, the situation is unlikely to change anytime soon.

Previous research undertaken at FPInnovations, PAPRICAN Division focused on determining the shelf-life of mountain pine beetle-killed wood for pulp and paper operations (Trent et al. 2006; Dalpke et al. 2008). FPInnovations found that a shelf-life of up to 10 years can be expected for kraft pulp mills without any significant influence on pulp properties. For mechanical pulp (TMP) producers, FPInnovations, PAPRICAN Division found a small but manageable drop in pulp strength, and a more pronounced influence on sheet structure (sheet density and roughness) of handsheets (Dalpke et al. 2008; Hu et al. 2009A). Also, preliminary tests on TMP made from late-grey-stage wood revealed a potential increase in linting propensity, which is a concern for mills.

These preliminary results corroborate the industry experience of deteriorating runnability and print quality over the last few years. Because spruce–pine–fir (SPF) is a superior fibre mix that can and is used to produce high-value printing grades, any possible influence on sheet structure and printing performance, including linting propensity, is a concern. Maintaining printing performance is critical for TMP producers to maintain competitiveness and retain customers. In order to avoid or overcome paper-quality problems, more additives can be used; these incur higher costs. Runnability problems that lead to decreased production constitute another economical impact.

It is currently not known to what extent printing-paper-quality issues are related to changes in incoming-fibre quality or to changes in processing when using mountain pine beetle-killed wood. For example, previous work has identified possible changes in bleaching protocols that may help to maintain brightness when using blue-stained wood (Hu et al. 2009B). However, changes in the use of bleaching chemicals influence fibre quality in ways only indirectly related to the effects of mountain pine beetle infestation. With both factors—fibre quality and process changes—likely influencing production and quality, research was needed to determine how fibre and chip quality of beetle-killed wood relates to changes in printing-related paper properties, taking changes in process conditions into account as well. The resulting knowledge provides better understanding of the interactions between process conditions and ensuing changes in fibre quality when processing beetle-killed wood, which in turn helps mills optimize overall processing conditions, instead of adjusting single process variables. Different strategies and scenarios of how to deal with beetle-killed wood, based on the incoming-chip quality, can then be developed to support continued production of high-value mechanical paper grades from SPF fibre harvested from beetle-infested regions.

Establishing relationships between fibre quality, process conditions, and paper quality is difficult due to the multitude of process conditions and interactions that each influence the other. For a sensible analysis, a complete dataset with a sufficient amount of data is required. The approach

chosen for this study was to collect incoming-wood-quality data, final paper-quality data and process data within one mechanical pulp mill over a period of two to three months. Data were collected from existing monitoring devices and through regular sampling and testing methods. In addition to existing monitoring devices, FPInnovations, PAPRICAN Division's online chip sensor was installed for the data-collection period. With this sensor, which is based on near-infrared techniques (Hsieh et al. 2006), monitoring wood quality on a continuous basis became possible. The partnering mechanical pulp mill produces high-quality printing papers and has tight requirements for pulp quality. In addition to data collection in the mill, laboratory studies established the influence of changing bleaching protocols on fibre quality.

The data were used to build models to predict the influence of beetle-related changes in wood and fibre quality on selected quality attributes, taking into account possible process changes. The models can be used to develop better understanding of best practices when pulping beetle-killed wood. If implemented, these would help to enable mills to use beetle-killed wood without excessive penalties in processing cost and resulting paper quality.

The laboratory studies of the effect of beetle-killed wood on bleaching and multivariate modeling of the effect of chip properties and TMP operating conditions on unbleached TMP properties are described in this report. In the first research component (Research Component 1: Influence of changing bleaching protocols on mechanical pulp quality), differences in the bleaching response due to the use of beetle-killed wood and to changing bleaching protocols were investigated. Unbleached pulp made from green, unattacked lodgepole pine trees and from grey-stage beetle-killed lodgepole pine trees were bleached under different conditions, and handsheets were formed and tested to determine their physical properties. In the second component, Research Component 2: Chip-Sensor Calibration and Measurements, the online chip sensor was set up at the mill and calibrated. Chip samples and their corresponding near-infrared absorbance spectra from the sensor were collected. The chips were analysed for bark, wood species, blue stain, density, moisture, brightness and extractives. The PLS 2 (projection to latent structures) calibration models were built, relating measured spectra to measured chip properties.

In the third component (Research Component 3: Modeling the relationship between chip properties and TMP properties), PLS 2 models were built, relating chip properties and TMP operating variables to unbleached TMP properties: CSF (Canadian standard freeness), tensile breaking length, bulk and brightness. Chip-sensor spectra and TMP operating data were collected for three periods: May 1 to 16, May 30 to June 16, and September 26 to October 29, 2009. PLS models were made for each of the three periods and for all three periods combined. Because no effect of chip-property variability on unbleached TMP properties was detected, the PLS model experiment was not extended to determine the effect of chip properties on bleached TMP and finished paper properties.

2 Research Component 1: Influence of changing bleaching protocols on mechanical pulp quality

2.1 Backgound

Industrial bleaching of mechanical pulps involves using mainly alkaline hydrogen peroxide (Presley and Hill 1996) or sodium hydrosulphite (Ellis 1996). Alkaline hydrogen peroxide pulping can achieve a brightness gain of up to 25 ISO (International Organization for Standardization) brightness points; however, it reduces pulp yield by 2%–5%, affects pulp properties, and increases the chemical oxygen demand of effluents due to the oxidative degradation of lignin and hemicelluloses (Brauer et al. 2001). Conversely, sodium hydrosulphite is a selective brightening agent that carries few penalties, but the maximum brightness gain is around 10 ISO brightness points. Both bleaching agents are used in mechanical pulp mills in

Canada. Peroxide treatment is usually reserved for mechanical paper that requires high brightness, most mechanical paper is bleached with the cheaper hydrosulphite.

One of the main problems in using mountain pine beetle-killed wood in mechanical pulping operations is the resulting initial low brightness of the pulp, which is caused by the blue stain in the wood. The impact of blue stain on pulp brightness and bleachability has been studied extensively (Hu et al. 2006, 2007); however, little work has been done on determining the effects of peroxide or hydrosulphite bleaching on pulp quality other than brightness. Also, previous work has shown that adjusting bleaching protocols can improve the bleaching response of mechanical pulp made from beetle-killed wood, but it can also affect pulp quality. The objective of this small laboratory study was to determine if pulp made from beetle-attacked wood reacts differently to bleaching than pulp made from green wood, and if changes in bleaching protocols in mechanical pulp mills in British Columbia will affect mechanical pulp quality.

2.2 Materials and Methods

2.2.1 Experimental

A pulp made from green, unattacked lodgepole pine trees and a pulp made from grey-stage beetle-killed lodgepole pine trees were bleached under different conditions, and handsheets were formed and tested to determine the physical properties of the pulp. Bleaching protocols were determined in consultation with the partner mill for this study. The protocols were chosen to represent conditions that were either typical before the mill started to use beetle-killed wood, that are now used to bleach beetle-killed wood, or that the mill sees as necessary to adjust to the new reality of using an increasing amount of blue-stained chips.

Sample origin

The two pulps used in this experiment were obtained from an earlier study (see Dalpke et al. 2008 for a description of log sampling and pulping procedures).

Sodium hydrosulphite bleaching

Sodium hydrosulphite (Y) bleaching of the green pulp involved using a hydrosulphite charge of 0.6%, which represents bleaching conditions that were used before the mill started to use beetle-infested wood. Hydrosulphite charges of 0.9% and 1.5% were used for the grey-stage pulp. A charge of 0.9% is typically used by the mill (up to 90% of the wood the mill receives is beetle killed); 1.5% is considered a maximum that could be used if further brightness improvement is required. If only brightness measurement was required, 12 g of pulp [oven-dried (o.d.) charge] was bleached. If physical testing was required, an additional 48 g was bleached. Only the pulp bleached at 1.5% charge was used for physical testing. It is well known that hydrosulphite bleaching has minimal effect on pulp properties except brightness; therefore, one sample point for physical testing was considered sufficient. For the same reason, it was not considered necessary to bleach and test the grey-stage pulp at a similar charge as the green pulp. It was decided that only if the few testing points showed any unexpected effect on pulp quality would additional testing points be used for bleaching and physical testing.

All hydrosulphite bleaching was conducted under similar conditions using a commercial, powder sodium hydrosulphite, Virwite S342 (Chemtrade Logistics, Trois-Rivières, Quebec) at selected charges (Table 1). Bleaching procedures followed those used in previous studies (Hu et al. 2007). Starting and end pH were measured and recorded. Resulting brightness was determined for all samples as the average of brightness measurement of three 200 g/m^2 handsheets prepared without whitewater recirculation.

Table 1. Sodium hydrosulphite (Y) bleaching conditions.

Sample	Temperature (°C)	Time (min)	Consistency (%)	Y brand[a]	Y charge (%)	Handsheets done
Green	75	60	4.2	Virwite S342	0.6	Yes
Grey-stage	75	60	4.2	Virwite S342	0.9	No
Grey-stage	75	60	4.2	Virwite S342	1.5	Yes

[a]Chemtrade Logistics, Trois-Rivières, Quebec.

Chelation and alkaline peroxide bleaching

The green sample was bleached at a charge of 5.5% peroxide (H_2O_2), which is consistent with procedures used before the beetle infestation. A grey-stage sample was also bleached at 5.5% peroxide, a charge that is still commonly used at the mill. Additional samples were bleached at 6.5%, 7.5%, and 8.5% peroxide to determine how much brightness improvement could be achieved. Twelve grams (o.d.) of pulp was bleached for brightness measurement; an additional 48 g (o.d.) was used to make handsheets. If needed, another 24 g (o.d.) was used to produce enough bleach filtrate to measure chemical and biological oxygen demand (COD/BOD). Handsheets were formed, and physical testing was done only for the 5.5% and 8.5% peroxide charges. This allowed comparisons to the green sample to be made and provided indication of how the pulp changed with increasing bleaching charge.

Prior to bleaching, all samples were subjected to a chelating stage to bind metal ions that would otherwise interfere with bleaching. Chelating was done with 0.135% DTPA-5Na at a consistency of 4% and a temperature of 75° C, for 15 min. Following chelation, bleaching was done under conditions shown in Table 2. The procedures for chelating and bleaching are described in Hu et al. 2007. Resulting brightness was determined for all samples as the average of brightness measurement of three 200 g/m^2 handsheets prepared without whitewater recirculation.

Table 2. Alkaline peroxide (H_2O_2) bleaching conditions.

Sample	Temperature (°C)	Time (min)	Consistency (%)	H_2O_2 (%)	NaOH (%)	Na_2SiO_3 (%)	DTPA-5Na (%)	Handsheets done
Green	75	180	20	5.5	4.0	3.0	0.135	Yes
Grey-stage	75	180	20	5.5	4.0	3.0	0.135	Yes
				6.5	4.8			No
				7.5	5.2			No
				8.5	5.5			Yes

Physical testing

For selected samples (Tables 1 and 2), handsheets (60 g/m^2) were prepared with whitewater recirculation to minimize the loss of fines. Physical testing was performed according to PAPTAC (Pulp & Paper Technical Association of Canada) standard procedures, and included strength, optical, and sheet structural tests. Handsheet roughness was measured by a Sheffield instrument, and the values obtained were expressed in Sheffield Units (SU). Physical testing data for the unbleached samples were available from a previous study (Dalpke et al. 2008). Fibre length for the pulp samples was determined with a Fibre Quality Analyzer instrument (Optest). Additionally, Bauer-McNett fibre classifications were determined for some of the peroxide-bleached pulps.

2.2.2 Chemical oxygen demand/biological oxygen demand requirements

For the peroxide-bleached samples used for physical testing (green: 5.5%; grey-stage: 5.5% and 8.5%), the COD/BOD of the bleach filtrates was determined according to PAPTAC standard procedures.

2.3 Research Component 1 Results and Discussion

2.3.1 Sodium Hydrosulphite Bleaching

The brightness values achieved with sodium hydrosulphite (Y) bleaching were compared against unbleached brightness values (Table 3). The unbleached brightness of the grey-stage pulp was about 10 points lower than that of the green pulp. Such differences have been reported previously (Hu et al. 2008). The brightness of the grey-stage pulp after bleaching was still considerably lower than that of the green pulp, even when higher charges were used.

Table 3. Sodium hydrosulphite (Y) bleaching results: ISO brightness results (%).

Sample	Unbleached	Y-charge 0.6%	Y-charge 0.9%	Y-charge 1.5%
Green	60.4	65.9		
Grey-stage	49.9		56.1	56.9[a]

[a]Brightness value is the average for pulps from small- and large-scale bleaching.

As expected, hydrosulphite bleaching had little to no effect on the physical properties of either the green or grey-stage pulp (Table 4). Although there were small differences in some properties between the unbleached green and grey-stage pulp, they were due to the natural variability in the lodgepole pine resource (Dalpke et al. 2008). Bleaching did not change the properties of either the green or grey-stage pulp to any significant extent, and small differences between the unbleached and bleached samples were likely due to analytical variability. The only marked difference was in roughness, which was high for the unbleached grey-stage sample, but lower for the bleached sample. We currently cannot explain this difference. One possibility is that the procedure used for bleaching (disintegration of pulp, high temperature) had an effect on roughness that was independent of that of the bleaching agent. Further work is needed to confirm this. Overall, with the possible exception of roughness, it can be concluded that changing hydrosulphite bleaching protocols to adjust for bleaching blue-stained pulp will not cause any changes in pulp properties other than brightness.

Table 4. Physical properties of unbleached and sodium hydrosulphite (Y) bleached pulps.

Sample	Green		Grey-stage	
Y bleaching charge (%)	0	0.6	0	1.5
Canadian standard freeness CSF (ml)	82	87	84	87
Apparent sheet density (kg/m^3)	390	369	366	361
Burst index ($kPa \cdot m^2/g$)	2.9	2.8	2.6	2.7
Tensile index ($N \cdot m/g$)	46	49	44	47
Stretch (%)	1.7	2.1	2.0	2.1
Tear index, 4 ply ($mN \cdot m^2/g$)	8.1	8.3	7.8	8.2
Brightness (%)[a]	59.0	65.9	51.6	56.2
ISO opacity (%)	94.8	93.9	98.1	97.5
Scattering coefficient (cm^2/g)	585	594	603	606
Sheffield roughness (SU)	145	162	264	172
Length-weighted average fibre length (mm)	1.57	1.56	1.58	1.53

[a]Brightness was measured on a stack of 60 g/m^2 handsheets made with whitewater recirculation.

2.3.2 Alkaline Peroxide Bleaching

As expected, brightness values of pulp samples after peroxide bleaching (Table 5) were better than those after hydrosulphite bleaching. However, at a bleaching charge of 5.5%, the ISO brightness of the grey-stage pulp was still about 4 points lower than that of the green pulp, and

even increasing the peroxide charge to 8.5% did not bring the brightness of the grey-stage pulp up to that of green pulp at 5.5%, although the difference decreased to about 1 point.

Table 5. Alkaline peroxide (H_2O_2) bleaching results: ISO brightness results (%).

Sample	Unbleached	H_2O_2-charge			
		5.5%	6.5%	7.5%	8.5%
Green	60.4	77.9[a]			
Grey-stage	49.9	73.4[a]	74.3	75.3	76.9[a]

[a]Brightness value is the average for pulps from small- and large-scale bleaching.

Physical properties of pulp are affected significantly by peroxide bleaching due to the oxidation of lignin and alkali-induced generation of carboxylic acid groups in hemicelluloses. It is commonly known that tensile and burst index and thus sheet strength increase with these effects, which is beneficial. However, bulk (the inverse of sheet density) and opacity both decrease, which is undesirable for mechanical pulp because it is commonly used to produce printing paper. Tear strength and sheet roughness also decrease. Physical properties of peroxide-bleached pulps are shown in Table 6. Tensile index, sheet density, and opacity are also shown in Figures 1 to 3, respectively. What is noticeable from these figures, and what is true for other properties (except for brightness), is that the response of the grey-stage and green samples to bleaching was about the same at similar bleach charges. Differences in the amount of increase or decrease in a specific property were not significant when comparing green and grey-stage pulp. An exception was roughness, which decreased more in the grey-stage than the green pulp; however, it was also much higher in the unbleached grey-stage than green sample, as discussed earlier. Peroxide bleaching may well have an effect on roughness, but the different responses of green and grey-stage pulps require further investigation, similar to what has been discussed for the hydrosulphite bleached samples. What is also noticeable is that for the grey-stage pulp, which was tested at two different bleaching charges, most of the change in physical properties occurred when the pulp was bleached with 5.5% peroxide. Increasing the bleaching charge to 8.5% did not cause much additional change in physical properties.

Table 6. Physical properties of unbleached and alkaline peroxide (H_2O_2) bleached pulps.

Sample	Green		Grey-stage		
H_2O_2 bleaching charge (%)	0	5.5	0	5.5	8.5
Canadian standard freeness CSF (ml)	82	90	84	83	94
Apparent sheet density (kg/m^3)	390	441	366	437	460
Burst index (kPa•m^2/g)	2.9	3.3	2.6	3.4	3.6
Tensile index (N•m/g)	46	56	44	60	63
Stretch (%)	1.73	2.25	2.02	2.46	2.50
Tear index, 4 ply (mN•m^2/g)	8.1	7.4	7.8	6.8	6.7
Brightness (%)[a]	59.0	77.3	51.6	73.0	77.3
ISO opacity (%)	94.8	84.8	98.1	85.5	83.3
Scattering coefficient (cm^2/g)	585	510	603	491	450
Sheffield roughness (SU)	145	115	264	123	125
Length-weighted average fibre length (mm)	1.57	1.54	1.58	1.54	1.54
Bauer-McNett fibre fractions					
R[b] 14 (%)	9.5	11.8	9.6	12.7	N/A
R 14/28 (%)	30.8	29.1	30.7	29.4	N/A
R 28/48 (%)	18.1	19.1	17.4	19.1	N/A
R 48/100 (%)	9.9	10.1	9.5	10.2	N/A
R 100/200 (%)	5.3	4.8	5.2	4.7	N/A
Pass 200 (%)	26.5	25.2	27.6	24.0	N/A
R - 48 Fraction (%)	58.4	59.9	57.7	61.1	N/A

[a]Brightness was measured on a stack of 60 g/m^2 handsheets made with whitewater recirculation (i.e., containing more fines); [b]R stands for retention.

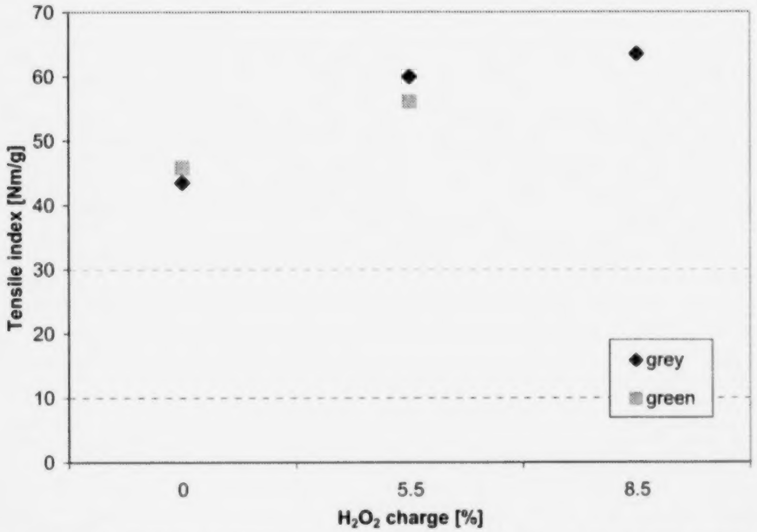

Figure 1. Tensile index of unbleached and peroxide (H_2O_2) bleached pulps.

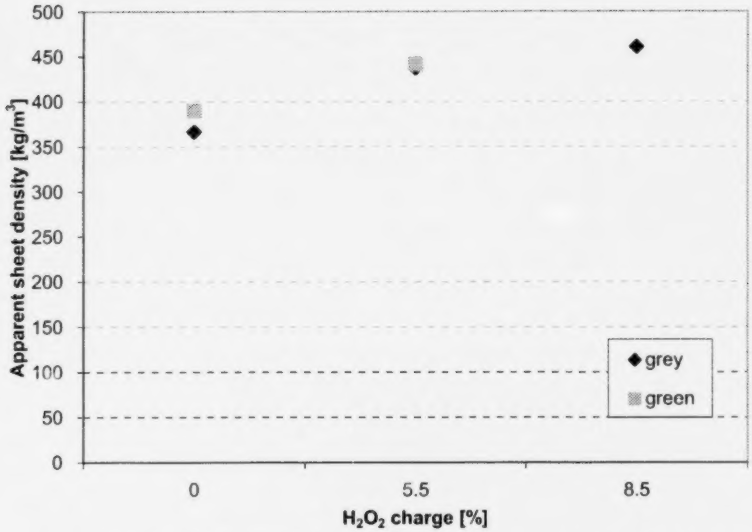

Figure 2. Apparent sheet density of unbleached and peroxide (H_2O_2) bleached pulps.

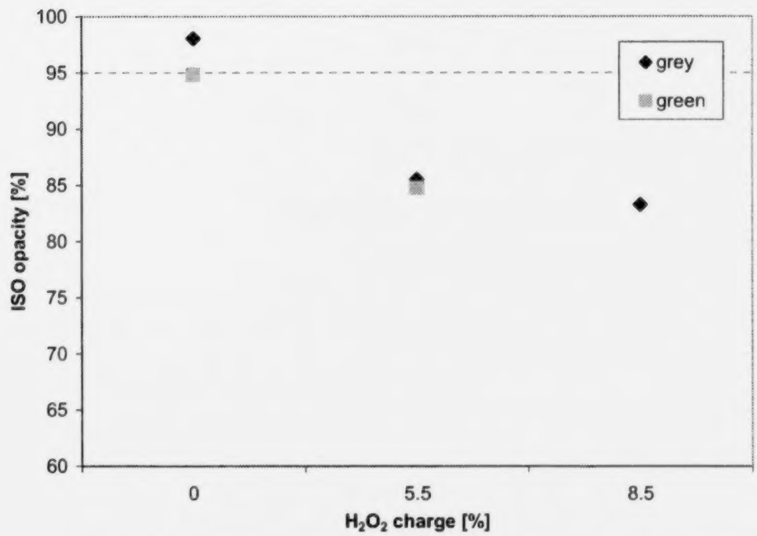

Figure 3. Opacity of unbleached and peroxide (H_2O_2) bleached pulps.

COD/BOD values of selected samples are shown in Table 7. Measures of COD/BOD of the bleach filtrates show the additional load on effluent from bleaching. They are also an indication of yield loss, which is otherwise difficult to measure on small laboratory bleaching samples. Differences between the green and grey-stage samples at 5.5% are within the range of natural/analytical variability, but the grey-stage sample at 8.5% shows an increase in COD/BOD content.

Table 7. Alkaline peroxide (H_2O_2) bleaching results: chemical and biological oxygen demand (COD/BOD) of bleach filtrates.

Sample - H_2O_2 charge	Green - 5.5%	Grey stage - 5.5%	Grey stage - 8.5%
COD (mg/l)	1,748	1,951	2,414
BOD (mg/l)	743	713	790

2.4 Research Component 1 Conclusions

For sodium hydrosulphite bleaching, changes in pulp properties other than brightness due to changes in bleaching conditions (hydrosulphite charge) are minor and not likely to be seen in a mill setting. Roughness seems to be affected more than brightness, but this needs further investigation. Also, there is no difference in bleaching response of green and grey-stage samples in terms of physical properties other than brightness. However, with alkaline peroxide bleaching, an effect from changing bleaching charge is observed, as expected.

Based on the results, it can be concluded that the effects of peroxide bleaching on physical properties, yield loss, and increase in effluent COD/BOD load are similar for green and grey-stage samples that are bleached under the same conditions. When the peroxide charge is increased, both physical properties and effluent load are affected. The change in physical properties needs to be considered, but is moderate. However, the increase in effluent load and the expected yield loss are significant and will be seen in the mill with changing peroxide-bleaching conditions.

3 Research Component 2: Chip-Sensor Calibration and Measurements

3.1 Chip Sensor Calibration

The on-line chip sensor was installed in the mill over the chip conveyor running between the chip screens and chip silos. The chip sensor measured near-infrared absorbance spectra, averaged every 5 s, to predict chip properties using PLS 2 (projection to latent structures) models that were calibrated to mill-specific conditions. Two calibration models were made because the sensor probe head was changed partway through the study, which caused an offset in the absorbance values.

For the first calibration model, 48 grab samples of chips were collected during the period from May 1 to June 16. These samples were analyzed for nine chip properties: bark, extractives, density, pine (blue), pine (clear), spruce, miscellaneous species, moisture, and brightness. Pine (blue) refers to chips that showed blue discoloration due to beetle attack; pine (clear) chips did not show blue discoloration. Chip-sampling times were used to match the relevant spectra to with the appropriate calibration samples. Spectra were collected for about 1 min for each chip sample. Multivariate software was used to develop a PLS calibration model to predict the nine chip properties from the spectra. The calibration was updated after the sensor probe head was changed. It used the spectral and analytical data for the 48 chip samples from the first model and data for two additional grab samples taken on September 23. The RMSEE (root mean square of error of estimate) for the second calibration model is shown in Table 8.

Table 8. Second calibration model for the chip sensor.

	RMSEE	Cumulative Q^2
Bark %	0.11	0.34
Extractives	0.4	0.52
Density kg/m^3	11	0.14
Pine blue, fraction	0.06	0.55
Pine clear, fraction	0.06	0.49
Spruce, fraction	0.04	0.47
Misc. species, fraction	0.03	0.78
Moisture %	1	0.81
Brightness %	2	0.43

The cumulative Q^2 is the fraction of the variation of the response predicted by the model according to cross validation. It indicates how well the model predicts new data; a useful model has a large cumulative Q^2. In this case, Q^2 was large for only moisture and miscellaneous species content. The model predictions for moisture, miscellaneous species, pine (blue), and extractives are shown in Figures 4 to 7, respectively.

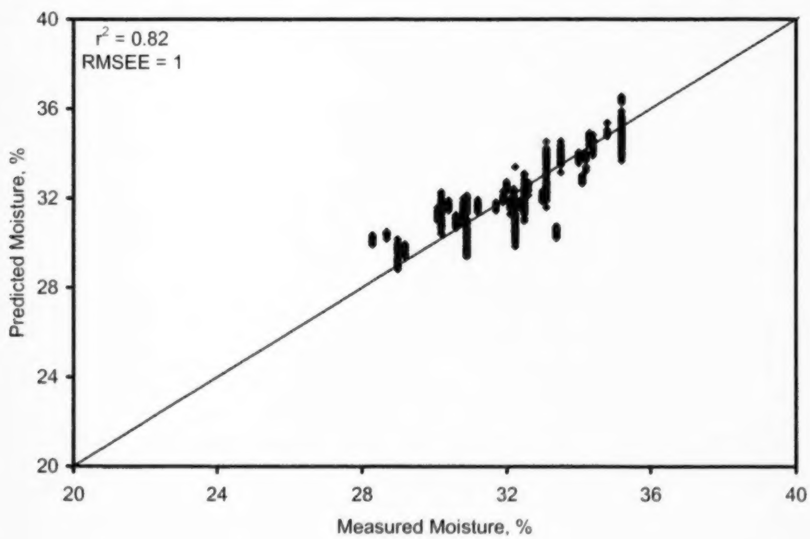

Figure 4. Predicted versus measured chip moisture for calibration samples.

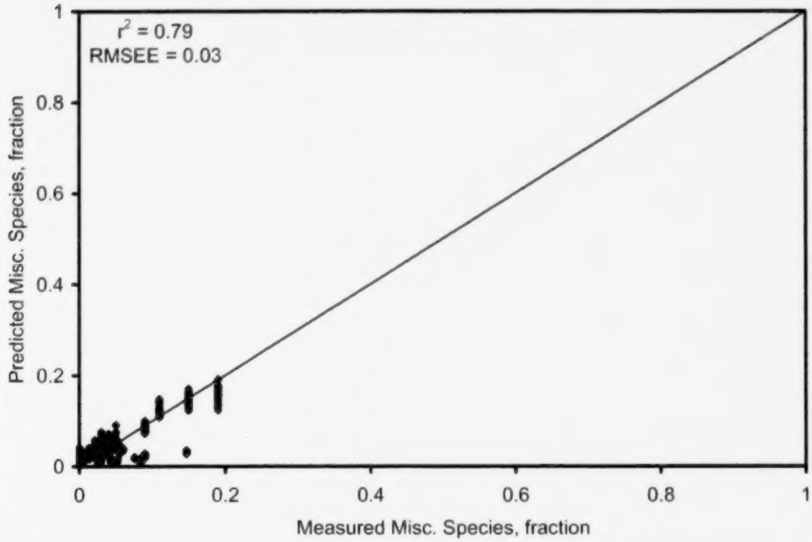

Figure 5. Predicted versus measured miscellaneous species content for calibration samples.

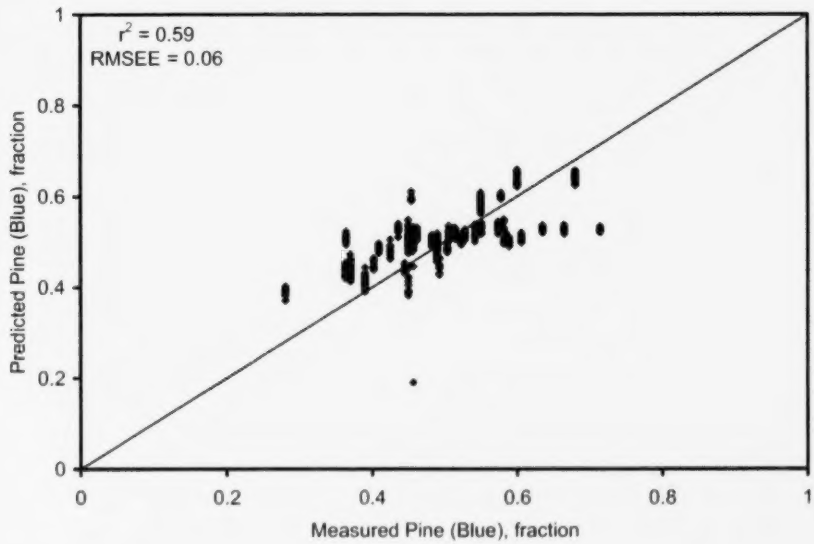

Figure 6. Predicted versus measured pine (blue) content for calibration samples.

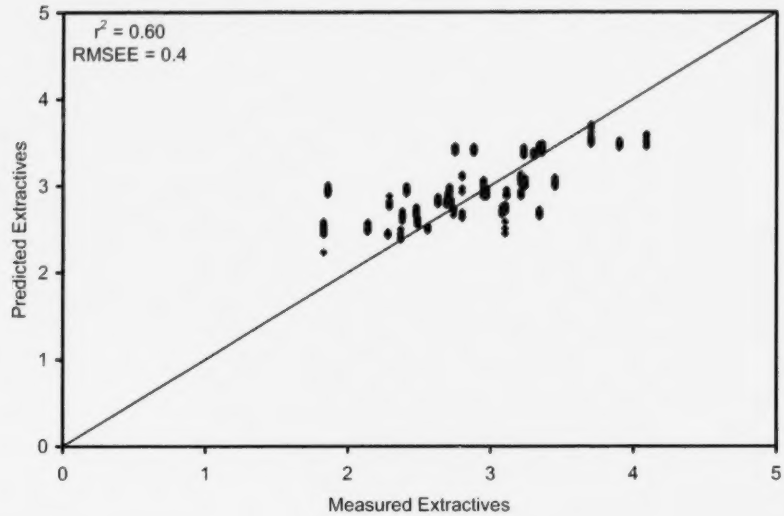

Figure 7. Predicted versus measured extractives content for calibration samples.

Some of the sensor calibrations were poorer than those found in other installations due to low variability in the calibration samples. For many variables, the variability in the predicted properties was similar to the estimation error in the calibration model. The predictive power of the model could be improved by using calibration samples with greater variability.

The performance of the calibration model was:

- good for moisture content and miscellaneous species content, accounting for about 80% of the variability in their values;
- fair for extractives content and pine (blue) fraction, accounting for about 60% of the variability in their values;
- poor for pine (clear) and spruce fractions, accounting for about 50% of the variability in their values, and;
- very poor for chip brightness, bark content, and chip density, accounting for only 15% to 40% of the variability in their values.

3.2 Chip Property Measurements

Chip sensor spectral data were collected for three periods: May 1–16, May 30–June 16, and September 26–October 29, 2009. These data were used to predict nine chip properties: bark, extractives, density, pine (blue), pine (clear), spruce, miscellaneous species, moisture, and brightness. Predictions for moisture, miscellaneous species, pine (blue), and extractives are shown in Figures 8 to 11, respectively, for all three periods. In each figure, the first quarter shows data from the May period, the second quarter shows data from the June period, and the remaining half shows data from the October period.

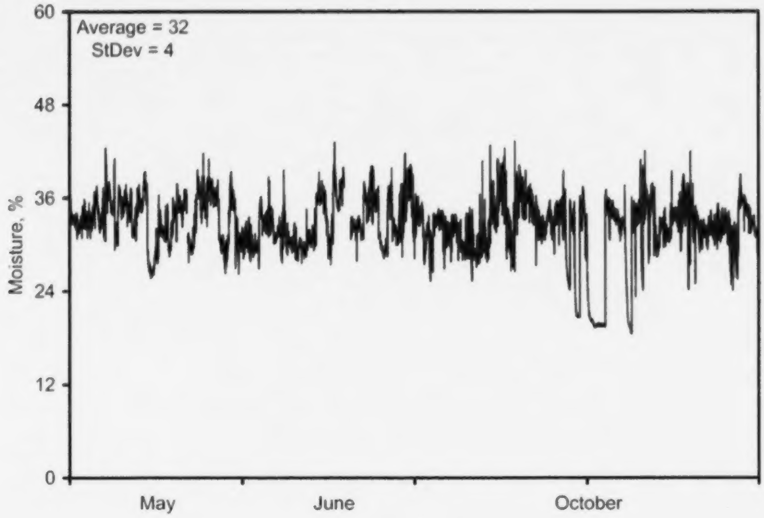

Figure 8. Chip moisture for all three periods.

The calibration model prediction quality for chip moisture was good. The predicted values for the three periods showed large variability with a standard deviation of 4%, larger than the estimated error for the model predictions.

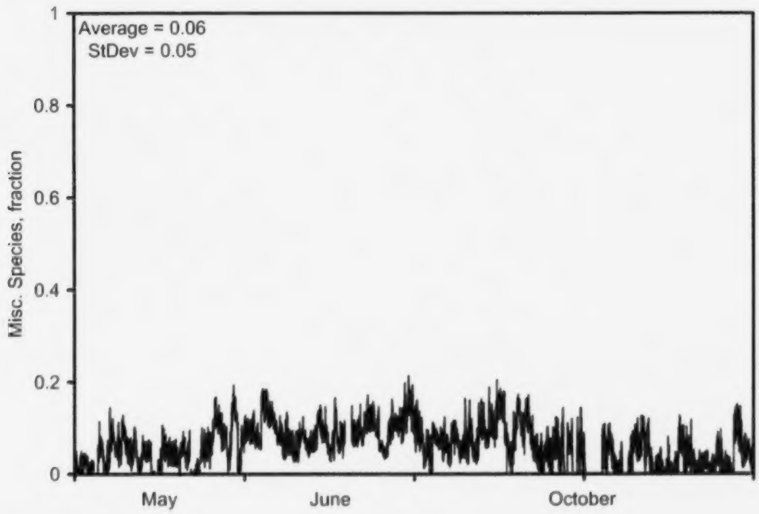

Figure 9. Chip miscellaneous species content for all three periods.

The calibration model prediction quality for chip miscellaneous species content was good. The predicted values for the three periods showed large variability with a standard deviation of 0.05, similar to the estimated error for the model predictions.

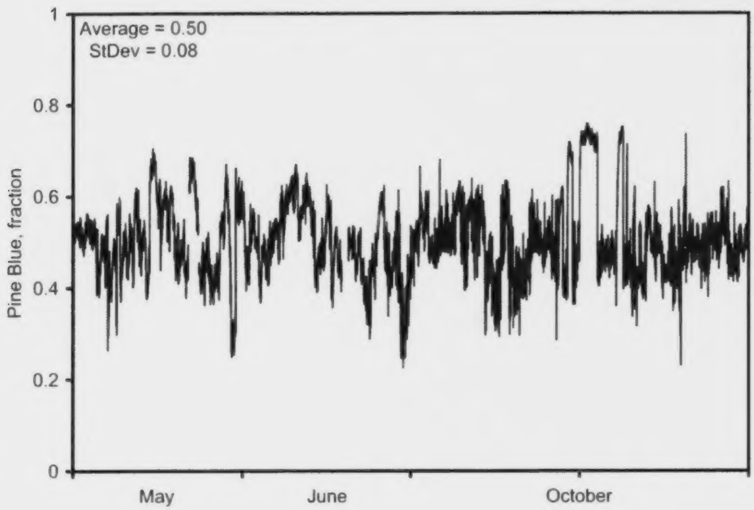

Figure 10. Chip pine (blue) content for all three periods.

The calibration model prediction quality for chip pine (blue) content was fair. The predicted values for the three periods showed large variability with a standard deviation of 0.08, similar to the estimated error for the model predictions.

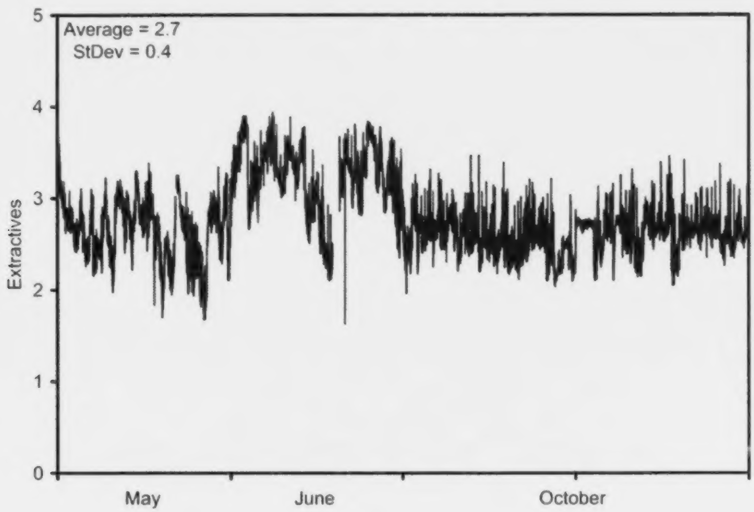

Figure 11. Chip extractives content for all three periods.

The calibration model prediction quality for extractives content was fair. The predicted values for the three periods showed large variability with a standard deviation of 0.4, similar to the estimated error for the model predictions.

There was large short-term variability in most predicted properties due to different barge loads of chips, and to variability within each load. Chip density and brightness had much smaller short-term variability than the other properties.

The long-term variability in chip properties was small (Table 9). There were no significant differences in average chip properties among the three measurement periods from May to October. However, except for moisture content, the variation in the predicted properties was similar to the estimation error in the calibration model. The chip sensor did not detect any change in the chip supply over the long term in terms of bark content, species mix, density, extractives, moisture, and brightness.

Table 9. Predicted chip properties: average ± standard deviation.

	May	June	October	All
Bark %	0.44 ± 0.08	0.58 ± 0.07	0.43 ± 0.12	0.47 ± 0.12
Extractives	2.6 ± 0.3	3.2 ± 0.4	2.6 ± 0.2	2.7 ± 0.4
Density kg/m^3	370 ± 7	373 ± 6	373 ± 7	372 ± 7
Pine (blue), fraction	0.50 ± 0.08	0.50 ± 0.08	0.50 ± 0.08	0.50 ± 0.08
Pine (clear), fraction	0.36 ± 0.07	0.29 ± 0.06	0.34 ± 0.09	0.33 ± 0.08
Spruce, fraction	0.10 ± 0.04	0.12 ± 0.03	0.11 ± 0.05	0.11 ± 0.04
Misc. species, fraction	0.04 ± 0.04	0.09 ± 0.03	0.05 ± 0.05	0.06 ± 0.05
Moisture %	34 ± 3	33 ± 3	32 ± 4	32 ± 4
Brightness %	48 ± 2	47 ± 2	46 ± 2	47 ± 2

3.3 Research Component 2 Conclusions

The chip sensor was calibrated for nine chip properties: bark, extractives, density, pine (blue), pine (clear), spruce, miscellaneous species, moisture, and brightness.

Some of the sensor calibrations were poorer than those found in other installations due to low variability in the calibration samples. For many variables, the variability in the predicted properties was similar to the estimation error in the calibration model. The predictive power of the model could be improved by using calibration samples with greater variability.

The measurement quality of the chip sensor was good for chip moisture content and miscellaneous species content, and fair for extractives content and pine (blue) content. The measurement quality was poor for the remaining five chip properties.

There was large short-term variability in most predicted properties during the three measurement periods; however, there was small variability in chip density and brightness.

The long-term variability in chip properties was small. The chip sensor did not detect any significant change in the chip supply over the long term in terms of bark content, species mix, density, extractives, moisture, and brightness.

4 Research Component 3: Modelling the relationship between chip properties and TMP properties

4.1 Overview

In the mill, the chip sensor was installed over the chip conveyor between the chip screen and chip silos. Chip sensor data were collected for three periods: May 1–16, May 30–June 16, and September 26–October 29, 2009. These data were used to predict nine chip properties: bark, extractives, density, pine (blue), pine (clear), spruce, miscellaneous species, moisture, and brightness.

Thermo-mechanical pulp (TMP) operating data and unbleached TMP property data were also collected for the three measurement periods. PLS 2 (projection to latent structures) models were made for each of the three periods, and for all three periods combined. The models were used to relate chip properties and TMP operating variables with four unbleached TMP properties: CSF (Canadian standard freeness), breaking length, bulk, and brightness.

4.2 Mill Process Description

The mill receives wood chips via barges. Chips are unloaded and transported into the mill by conveyor. All chips go through a screen to remove rejects and are then distributed to seven chip silos. These silos feed the five TMP refining lines.

Chips are washed, steamed, pressed, and then refined. Chip wash water and pressates are sewered. The pulp from all refiners is subjected to primary and secondary screening, and accepts go directly into the decker chest. Rejects are treated in a reject refiner. Accepts from the reject refiner also go to the decker for thickening before being mixed in the decker chest. Process water from the deckers is used to dilute stock ahead of the screens and after reject refining.

From the TMP plant, part of the pulp is pumped to a twin-wire press for dewatering. It is then mixed with bleach chemicals (peroxide bleaching) and put through the retention tower before being used in the paper mill. The other part of the pulp is bleached with sodium hydrosulphite, mainly due to capacity limits in the peroxide-bleach plant. This pulp is diverted before the twin-wire press, and chemicals are mixed directly into the pulp by injecting them into the pipe that is used to divert the pulp for hydrosulphite bleaching. The hydrosulphite-bleached pulp is used mainly for newsprint production, whereas the higher brightness peroxide-bleached pulp is used for the value-added, higher brightness grades.

The paper mill houses three paper machines: PM 9 produces mainly newsprint; PM 10 and PM 11 produce higher value grades. PM 10 produces the highest brightness grades, a grade similar to SC-A (supercalendered A grade) and has the least changeover in grades. It also does not use any de-inked pulp (DIP), whereas the other two paper machines use small amounts. PM 11 is also moving into higher brightness grades, but has more frequent grade changes than PM10. Each paper machine has its own approach system where mechanical pulp, reslushed kraft pulp, and DIP are mixed with additives according to grade recipe, and the stock is prepared for use in the paper machine. Whitewater is collected from the paper machines and is used for dilution within the paper machine whitewater system. Excess whitewater from the machines is used in the bleach plant and TMP plants.

4.3 Data Collection

Chip-property data were provided by the chip sensor. The sensor measured near-infrared absorbance at 5-s intervals during the three measurement periods. Spectral data were collected at 1-min intervals and were processed with the appropriate chip sensor calibration model to give

predicted values for nine chip properties: bark, extractives, density, pine (blue), pine (clear), spruce, miscellaneous species, moisture, and brightness.

The chip conveyor was intermittently filled with chips. The measurements when chips were present were determined from the near-infrared absorbance at 305 nm. Chips were present for lower absorbance values (< 1 at 305 nm; Figure 12), but were absent for higher absorbance values (> 1 at 305 nm). Data points when chips were absent from the chip conveyor were removed along with a few points where absorbance or predicted chip-property values were outside the normal range of values.

In order to relate the chip-property values to other mill data, the chip-property predictions were equally distributed over time for the measurement period. The chip-property data in the dataset were sampled at 5-min intervals.

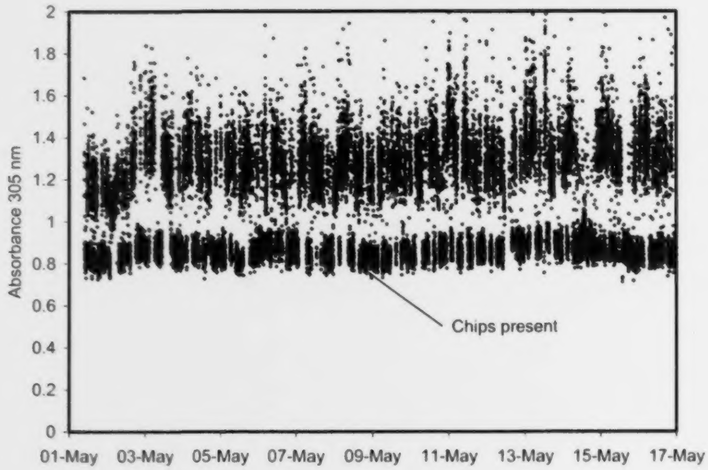

Figure 12. Chip sensor absorbance at 305 nm during the first period from May 1 to 16. Chips were present for lower values of absorbance.

The choice of which operating variables to monitor was based on an understanding of the mill processes and previous studies (Nobleza 1996; Ortiz-Cordova et al. 2006; Harrison et al. 2007). There were 31 operating variables: specific refining energy and plate time for primary and secondary refiners in Lines 1 to 5, TMP production for Lines 1 to 5, and refining power and plate times for the three reject refiners. Data for each line were removed when it was not running and for short periods during start-up and shutdown. Mechanical pulp operating data were interpolated at 5-min intervals from values in the mill's information system.

Because the study was investigating overall quality of pulp, not performance of individual refining lines, pulp quality was monitored in the TMP screen room. The following pulp properties were measured by an automatic PulpExpert: CSF, consistency, conductivity, pH, tensile strength, bulk, fibre length, fibre coarseness, fibre curl, shives content, and brightness. These measurements were taken at irregular intervals; the TMP property data were interpolated at 5-min intervals from values in the mill's information system.

4.4 PLS Model for TMP Properties

PLS 2 models were made to relate chip properties and TMP operating data to TMP properties using SIMCA-P. There were 40 X variables (Table 10). The Y variables were limited to four of the TMP properties (Table 11).

Table 10. X variables in the PLS models.

Chip properties	TMP operating variables		
Bark	L1 Pri. Energy	L3 Pri. Plate	L5 Pri. Plate
Extractives	L1 Pri. Plate	L3 Production	L5 Production
Density	L1 Production	L3 Sec. Energy	L5 Sec. Energy
Pine blue	L1 Sec. Energy	L3 Sec. Plate	L5 Sec. Plate
Pine clear	L1 Sec. Plate	L4 Pri. Energy	R1 Plate
Spruce	L2 Pri. Energy	L4 Pri. Plate	R1 Power
Misc. species	L2 Pri. Plate	L4 Production	R2 Plate
Moisture	L2 Production	L4 Sec. Energy	R2 Power
Brightness	L2 Sec. Energy	L4 Sec. Plate	R3 Plate
	L2 Sec. Plate	L5 Pri. Energy	R3 Power
	L3 Pri. Energy		

Table 11. Y variables in the PLS models.

CSF
Breaking length
Bulk
Brightness

Difficulty occurred in determining the lag between the chip properties and TMP properties caused by the chip handling system and chip storage. After the chip sensor, the chips are directed to seven chip silos that feed the five refining lines. The mill reports using 2560 m^3/d of chips to produce 950 t/d TMP (Pulp & Paper Canada 2008). Using the average production rates and chip storage volumes for the measurement periods, the retention time in the chip silos was about 48 h for all three periods. Looser chip packing in the chip silos would give a shorter retention time.

The effect of different lag times on the models was investigated using SIMCA-P (Figure 13). The chip sensor lag did not significantly affect the model performance as represented by $Q^2_{(cum)}$, the fraction of the measured variance explained by the model. The models explained about 40% of the variability in chip properties, which is typical when the process is controlled and the data are compromised by noise (Ortiz-Cordova et al. 2006).

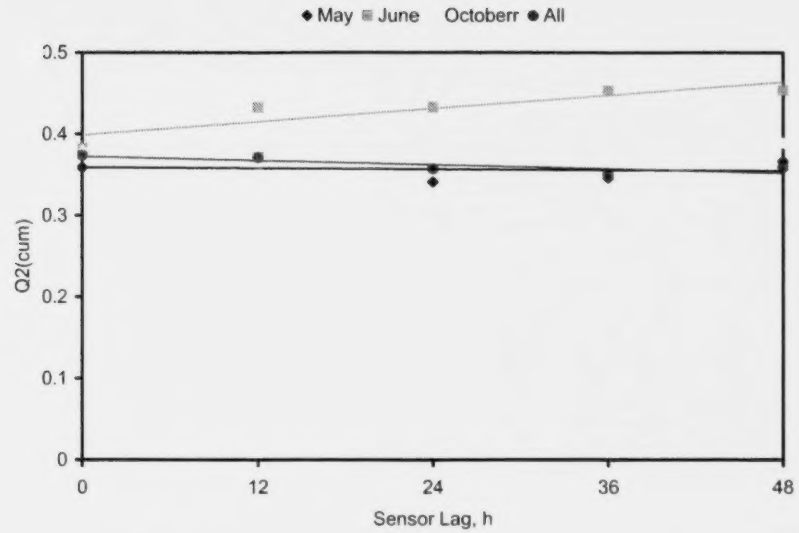

Figure 13. $Q^2_{(cum)}$ (Q2cum)versus chip sensor lag for the four PLS models

The predicted chip properties were lagged by 36 h in each PLS model to account for the delay between chip sensor measurements and TMP production. The chosen lag was less than the estimated 48-h retention time in the chip silos to account for looser chip packing retention time. The choice of lag time was not critical, as the model predictions for shorter or longer lag times were not significantly different.

4.5 Research Component 3 Results

The model parameters for the four PLS models are shown in Table 12. The model for the May period explained 35% of the TMP property variance; 65% of the variance was unexplained. The models for June and October explained 45% and 39% of the variance, respectively. The model for the all three periods combined explained 35% of the variance.

Table 12. PLS model parameters.

	May	June	October	All
X variables	40	40	40	40
Y variables	4	4	4	4
Chip sensor lag, h	36	36	36	36
Principal components	8	7	7	7
R^2X	0.693	0.699	0.762	0.621
R^2Y	0.349	0.458	0.386	0.350
Q^2(cum)	0.346	0.453	0.385	0.350

The variable influence on projection (VIP) values was determined for each model. Figure 14 shows the VIP values for the model for all three periods combined. The nine light bars are the chip properties; the 31 dark bars are the TMP operating variables. X variables with large VIP (greater than 1) are the most relevant for explaining the Y variables. The X variables with VIP values greater than 1 are shown in Table 13.

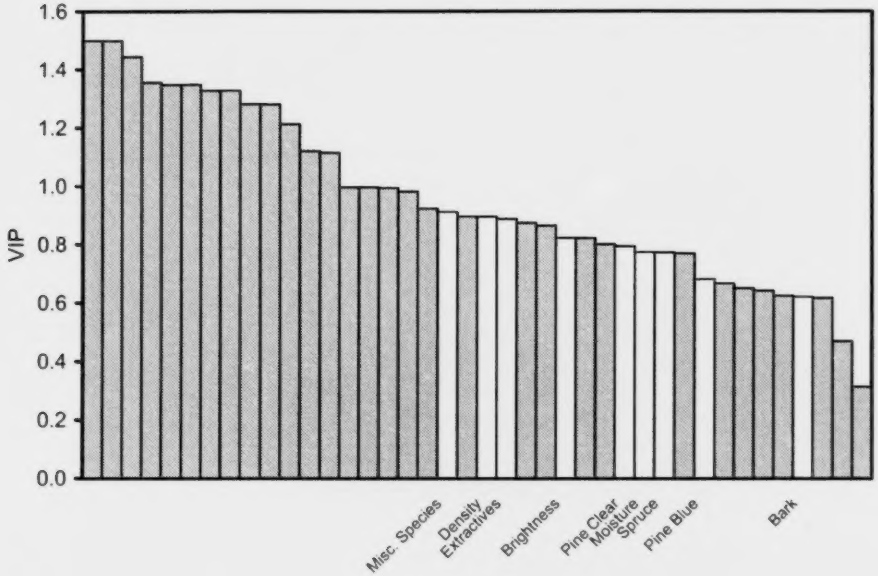

Figure 14. VIP values for the model for all three periods combined. Dark bars are TMP operating variables; light bars are chip properties.

Table 13. VIP values greater than 1 for the model for all three periods combined

	VIP		VIP
L1 Sec. Plate	1.50	L3 Pri. Plate	1.33
L1 Pri. Plate	1.50	L5 Sec. Plate	1.28
R1 Plate	1.44	L5 Pri. Plate	1.28
R3 Plate	1.36	R2 Plate	1.21
L4 Pri. Plate	1.35	R3 Power	1.12
L4 Sec. Plate	1.35	L3 Production	1.12
L3 Sec. Plate	1.33		

The variables that had the greatest effect on the model were TMP operating variables: plate time, refining power, and production. The VIP values for the nine chip properties were less than 1, and thus had little effect on the model. The VIP values for the three individual periods showed similar distributions, with the TMP operating variables having the largest effect on the models. This is similar to a previous study in which the TMP operating conditions and pulp properties generally had larger VIP values than the chip properties did in a model of paper properties (Ortiz-Cordova et al. 2006).

Figures 15 and 16 show the measured and predicted CSF for all three periods combined. In Figure 15, the model used the TMP operating variables and the chip properties; in Figure 16, the model used only the TMP operating variables. The two predictions are very similar, indicating that CSF is affected predominantly by the TMP operating variables. Similarly, for the other TMP properties, Figures 17 to 22 show no difference in the predicted values with and without using chip properties. The predictions for each of the three individual periods were similar, with the TMP operating variables having the greatest effect on the models.

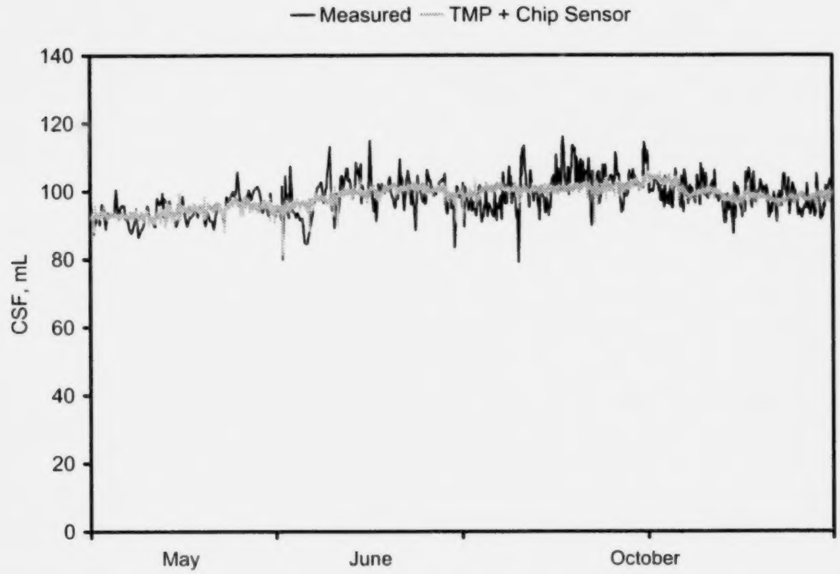

Figure 15. Measured and predicted CSF for all three periods combined using TMP operating variables and chip properties

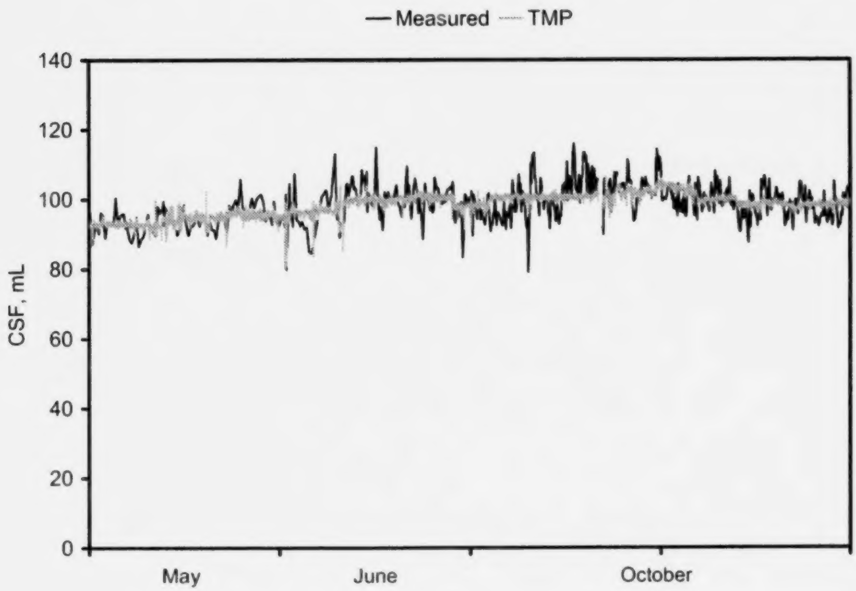

Figure 16. Measured and predicted CSF for all three periods combined using TMP operating variables only

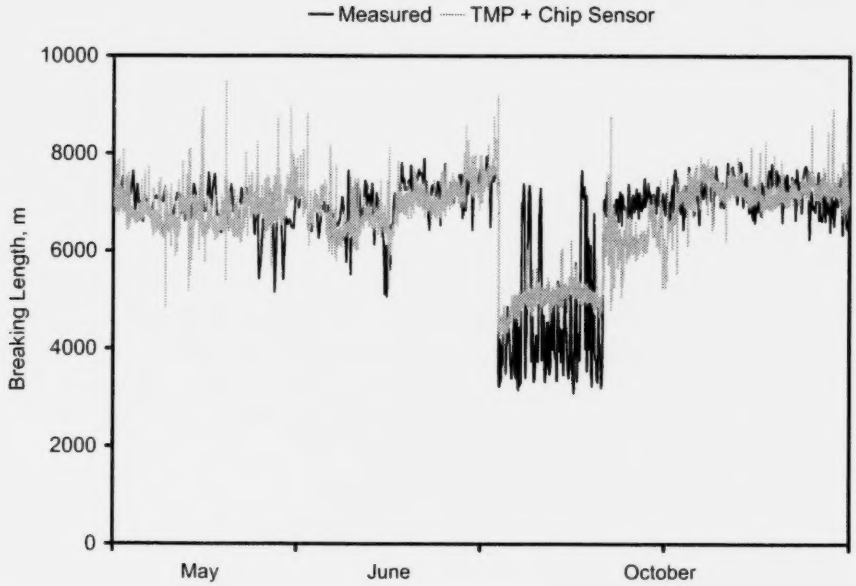

Figure 17. Measured and predicted breaking length for all three periods combined using TMP operating variables and chip properties

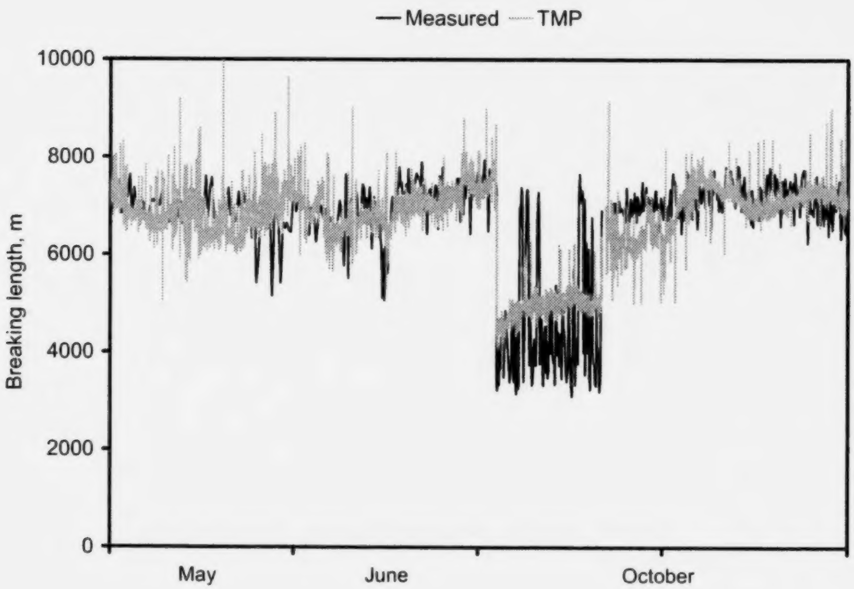

Figure 18. Measured and predicted breaking length for all three periods combined using TMP operating variables only

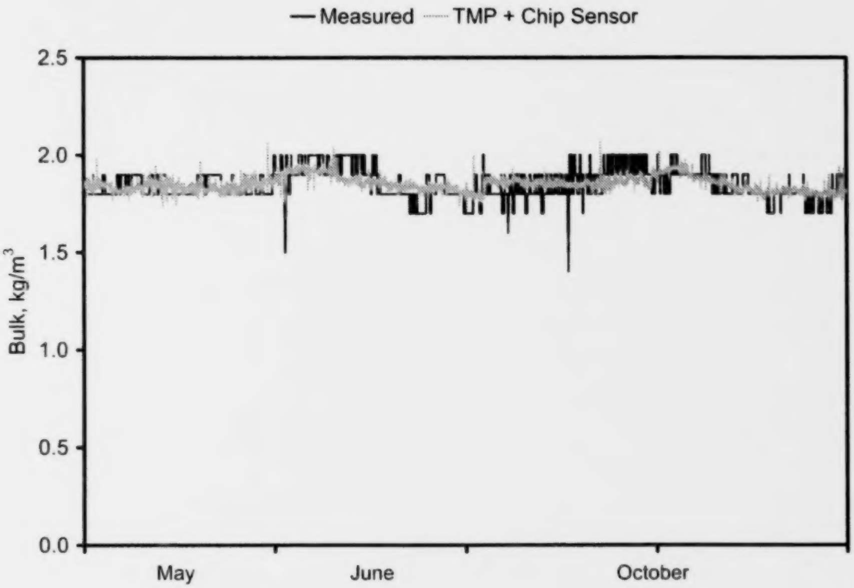

Figure 19. Measured and predicted bulk for all three periods combined using TMP operating variables and chip properties

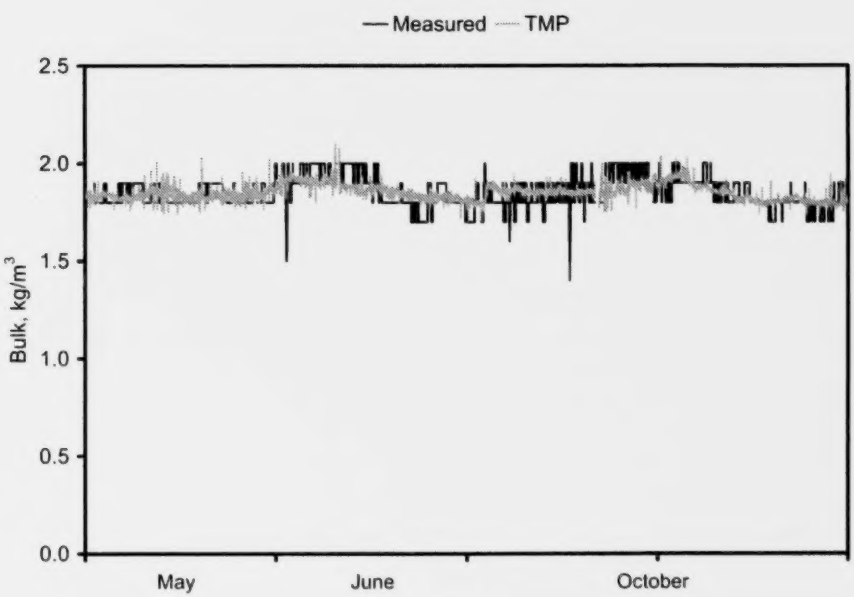

Figure 20. Measured and predicted bulk for all three periods combined using TMP operating variables only

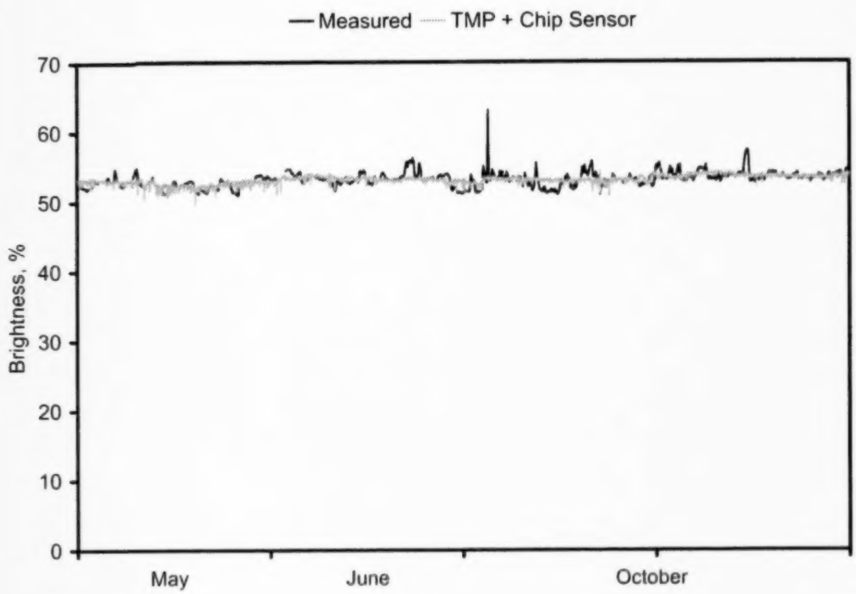

Figure 21. Measured and predicted brightness for all three periods combined using TMP operating variables and chip properties

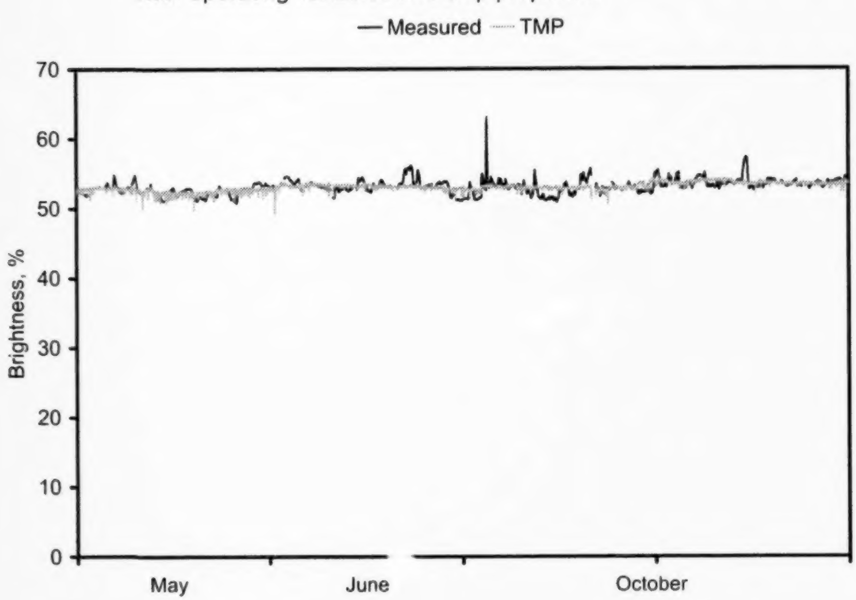

Figure 22. Measured and predicted brightness for all three periods combined using TMP operating variables only

The RMSEE (root mean square error of estimation) of the TMP properties for all three periods combined is shown in Table 14 for models using TMP operating variables and chip properties, and TMP operating variables only. The addition of the chip properties to the model did not improve the model predictions.

Table 14. RMSEE (root mean square error of estimation) for all three periods combined for predictions made using TMP operating variables and chip properties, and TMP operating variables only

	RMSEE	
	Without chip properties	With chip properties
CSF mL	4.08	4.21
Breaking length km	657	668
Bulk cm^3/g	0.0673	0.0681
Brightness %	0.846	0.851

4.6 Discussion

The variation in the chip properties had little effect on the variation in the TMP properties. There are two reasons for this: (1) the chip-handling system and storage between the chip sensor and the TMP operation dampened the effect of the short-term variability in the chip properties; and (2) the long-term variability in chip properties was small (Table 15). Figure 23 shows the chip moisture for all three periods. There is large variability over the short term due to different barge loads of chips, but little difference in the average moisture for the three measurement periods. Similarly, for the other chip properties, there was little difference in their average values among the three periods. The mill has a fairly constant chip supply in terms of species mix, density, moisture, and brightness.

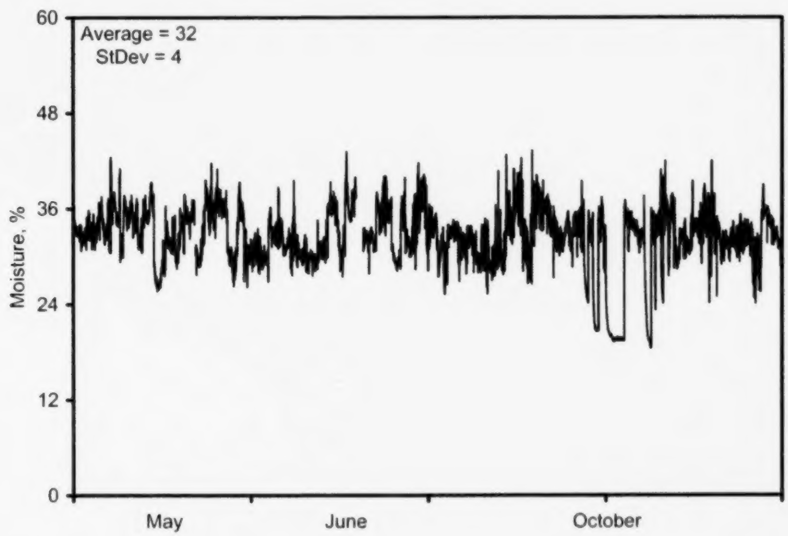

Figure 23. Chip moisture for all three periods

Table 15. Chip properties: average ± standard deviation

	May	June	October	All
Bark %	0.44 ± 0.08	0.58 ± 0.07	0.43 ± 0.12	0.47 ± 0.12
Extractives	2.6 ± 0.3	3.2 ± 0.04	2.6 ± 0.2	2.7 ± 0.4
Density kg/m^3	370 ± 7	373 ± 6	373 ± 7	372 ± 7
Pine blue, fraction	0.50 ± 0.08	0.50 ± 0.08	0.50 ± 0.08	0.50 ± 0.08
Pine clear, fraction	0.36 ± 0.07	0.29 ± 0.06	0.34 ± 0.09	0.33 ± 0.08
Spruce, fraction	0.10 ± 0.04	0.12 ± 0.03	0.11 ± 0.05	0.11 ± 0.04
Misc. species, fraction	0.04 ± 0.04	0.09 ± 0.03	0.05 ± 0.05	0.06 ± 0.05
Moisture %	34 ± 3	33 ± 3	32 ± 4	32 ± 4
Brightness %	48 ± 2	47 ± 2	46 ± 2	47 ± 2

4.7 Research Component 3 Conclusions

There was large short-term variability in most predicted chip properties, with the exception of chip density and brightness. However, the influence of short-term chip property variability on the unbleached TMP properties was small due to chip handling and storage between the chip sensor and the TMP operation, which resulted in the chips being mixed within the process and damped the effect of variability. The long-term variability in the chip properties from May to October 2009 was small, and thus had little effect on the variability of the unbleached TMP properties.

The unbleached TMP properties were strongly affected by operating conditions, such as refiner plate time, primary and secondary refining energies, reject refining power, and production. These had a stronger effect on TMP quality than did the incoming-chip quality. As a result, no effect of the variation in chip properties on unbleached TMP properties could be detected; therefore, the PLS model was not extended to determine the effect of the variation in chip properties on bleached TMP and finished paper properties.

Further work is needed to determine the effect of beetle-wood chip quality on unbleached TMP and finished paper quality at this mill. At this particular mill, no effect of chip properties (and thus the use of beetle killed-wood) on pulp variability was observed, due to the chip-handling system and the small long-term variations; however, this may not be the case at other mills. The short-term variation in chip moisture was likely caused by the use of different ratios of beetle-killed wood. If such short-term variations are not damped out, variations in pulp properties are likely (Dalpke et al. 2008). Using the modelling approach of this study in other settings where short-term variations remain after chip handling could determine the relative importance of variations in chip properties and TMP operating conditions. Also, long-term variations may exist but may not have been captured during the limited data collection periods used in this study. Extended use of the chip sensor (e.g., over a 12-month period) to document possible long-term variations would reveal such variations in this or other mills.

5 Project Conclusions

Peroxide bleaching of grey-stage beetle-killed lodgepole pine required an increased peroxide charge to reach a brightness target, affecting physical properties moderately and effluent load significantly.

For sodium hydrosulphite bleaching of green and grey-stage wood, the changes in pulp properties, other than brightness, that are due to changes in hydrosulphite charge were small and are not likely to be felt in a mill setting.

There was large short-term variability of most predicted chip properties, with the exception of chip density and brightness. However, the influence of short-term chip-property variability on the unbleached mechanical pulp properties was small due to the chip handling and storage between the chip sensor and the pulping operation. The handling and storage caused the chips to become mixed within the process and damped the impact of variability.

The long-term variability of chip properties was small; the chip sensor did not detect any major changes in the chip supply over the long term, in terms of bark content, species mix, density, extractives, moisture and brightness.

The unbleached TMP properties were strongly influenced by operating conditions such as refiner plate time, primary and secondary refining energies, reject refining power, and production. These operating effects had a stronger impact on pulp quality than did the incoming-chip quality; because of this, no influence of the variation of chip properties on unbleached TMP properties could be detected, and the PLS model was not extended to determine the effect on bleached TMP and finished paper properties. Further work is needed to determine the impact of beetle-wood chip quality on unbleached TMP and finished paper quality at this mill.

Although no influence of chip properties (and thus the use of mountain pine beetle-killed wood) on pulp variability could be seen at this particular mill due to the chip-handling system and the small long-term variations, this is not necessarily true for other mills. The short-term variation in chip moisture is likely caused by the use of different ratios of beetle-killed wood. If such short-term variations are not damped out, variations in pulp properties are likely (Dalpke et al. 2008). Using the modelling approach of this work in other settings where short-term variations remain after chip handling, could determine the relative importance of variations in chip properties and TMP operating conditions. Also, long-term variations may exist, but may not have been captured during the limited data collection periods of this study. Extended use of the chip sensor (e.g., over a 12-month period) to document possible long-term variations would reveal such variations in this and other mills.

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